Chemical Process Control

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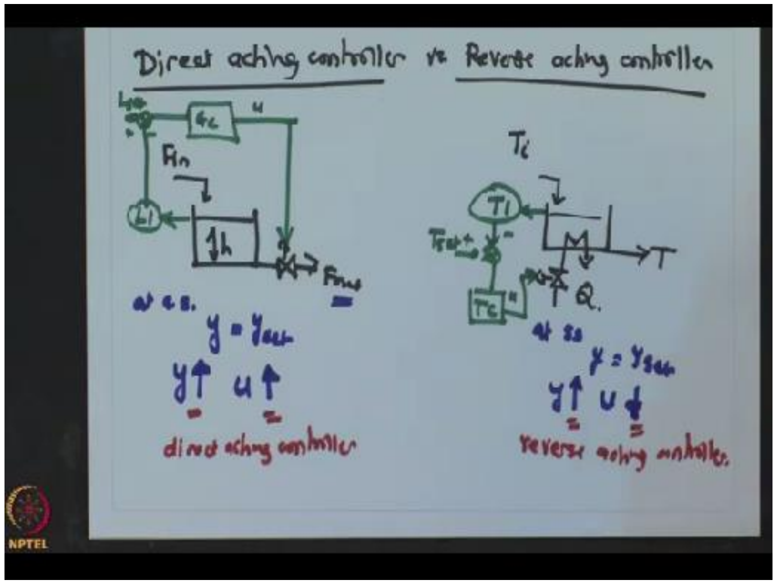
Lecture – 22
ON-OFF Control

Welcome back. We have seen how a feedback control implementation is done and what is the transfer function when we look at the closed loop of a system by using a feedback control. In this lecture, we will now look at what are the basic control actions which are present or possible when we try to implement a feedback control system or feedback control strategy.

Those are mainly proportional action, integral action and derivative action. We will look at what is the rationale behind each of those actions. We will then analyze the closed loop response of a system when the system is subjected to these controllers. And lastly, we will see what is the effect of controller parameters and what sort of dynamics does it have when we change some of the parameters of the control system.

Before moving forward, let me just clarify the actions of a feedback controller. There are two distinct types of actions which a feedback controller has and depending on the type of action, the controller parameters have to be chosen. If we choose that wrongly, then the controller will not be able to do the job for which it is installed. So we first need to look at whether the controller is going to be direct acting or reverse acting.



In order to motivate these, let me consider two implementations of feedback control. The first one is the same as what we had looked just a while back. It is the feedback control of level. We are trying to control this level with the disturbance. The way we do it is first measure the level. Accordingly, it is compared with the set value. That error goes to the controller and then that controller will take an action and make a change to the valve. Then finally, you will get the change into the manipulated variable which is 'F_{out}'.

Now let us consider a second example. Again the system we had considered earlier is the stirred heater or stirred tank heater where you have some feed coming in at temperature 'T_i' and you want to control the temperature inside this vessel to some value 'T' and that is done by changing the heat flow into this system.

In this case, if we want to implement feedback control, what we will be doing is we will first measure the temperature with temperature indicator. Then that will be compared with the desired value of set point and then it will go to the controller which is the temperature controller. The output of that controller will change this manipulated variable which may be the steam flow rate which will change the duty or the heat duty supplied to this particular system.

So, both of these are feedback control systems and I would like you to pause for a bit and try to see if there is any distinction or any difference between these two feedback controllers. I hope you were able to find the distinction between these two systems and if you have not, then let me go over it. In both the cases, let us look at what happens when at the steady state, you will have your output is equal to the set value.

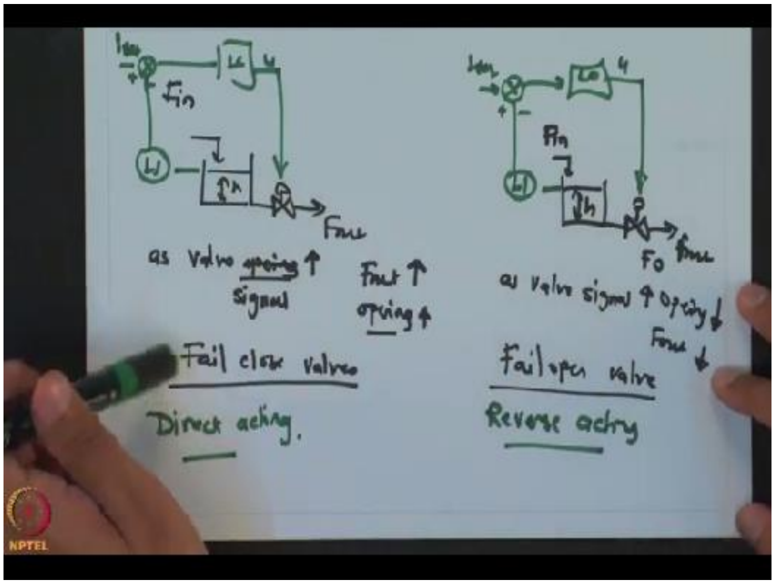
In both the cases, output will be equal to the set value. Let us say at some finite time because of some disturbance, this ‘y’ increases beyond the set point in both the cases. So in this case, as y increases which means the height inside this tank increases, what is the control action that is needed to maintain the level? That your output should also increase. So which is same as the controller output should also increase.

So if I represent ‘u’ as the controller output, then it has to increase when my height increases which ultimately result in increase in ‘F_{out}’. Now we will look at this case of the stirred tank heater. Let us say the ‘y’ increases beyond the set point that means the temperature inside this tank is above the desired value. Now what should the controller do? It should actually cut down on the heating duty supplied to the system. That means the controller output should decrease.

Now you can notice the difference between these two systems. In first example, an increase in the output causes increase in the controller output. Therefore, it is known as direct acting controller. In the second example, increase in the output causes a decrease in the controller output. Therefore, it is known as reverse acting controller. So it is very essential that know what is the type of action of the feedback controller whether it is direct acting or reverse acting. If you use a reverse acting controller to control the first process, you will realize that the level will never be maintained by any type of feedback controller.

Similarly, if for stirred heater system, I use the direct acting controller, again the system, this feedback system will never be able to maintain the temperature to its desired value. So the first and foremost thing before even deciding what type of a feedback control we want, what type of a feedback control action we need in terms of the proportional integral or derivative action.

The first thing you should be trying to find out is whether your system is going to be a direct acting or a reverse acting. This is not that straightforward when we look at the industrial implementations of systems because a same system may give you a direct or reverse action depending on the type of actuator which is inside the process. So we will try to explain this.



Let us say we have the same example of liquid surge tank. Here we considered that as the valve opening increases or I would say valve signal increases, 'F_{out}' increases because the valve opening increases. These types of valves are known as Fail close valves which means if there is no signal given to the valve, the opening will be 0 and the flow out of that valve will also be 0.

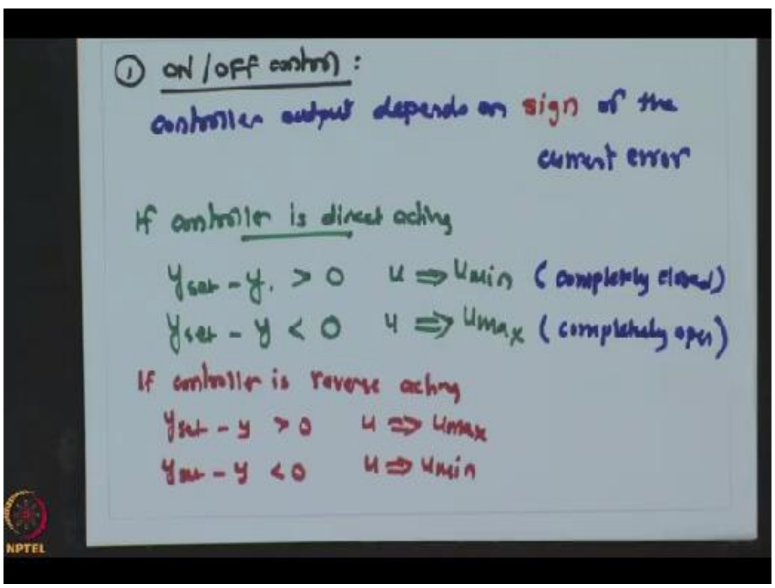
If that is the case and if we implement a feedback control on to this system, which will be of this form, then this feedback control system will be direct acting. But for the same system, if we have the valve which is known as the fail open valve. So the same system which is generally represented in its piping and instrumentation diagram by a small subscript F_o, so the implementation is exactly the same but what you now see is as the fail open type of valve, as valve signal increases, the valve opening decreases or that means 'F_{out}' decreases.

That is because when the valve does not have any signal, the valve is completely open or the valve has 100% opening. So if that is the case and you try to find out what happens when the height increases, in that case, you will realize that in order to increase 'F_{out}', the controller signal will have to reduce. And because of that, if it is a fail open valve, then the same feedback control system would be reverse acting.

You can see that same system, only difference is the actuator type. In one case, the actuator is fail close and this other case, the actuator is fail open. Just this small difference is going to make the controller to be either direct acting or reverse acting. And as I had said earlier, that if we use or mistakenly use this to be a direct acting controller, it will never be able to maintain the level.

As we look at the control systems, we will see why that is the case on a more mathematical, at a higher true mathematical analysis as well. So it is very important to know what is the type of the controller action.

Let us now look at what are the different type of control actions which are possible in feedback control. The first or the simplest control action, simplest in terms implementation is on-off control.



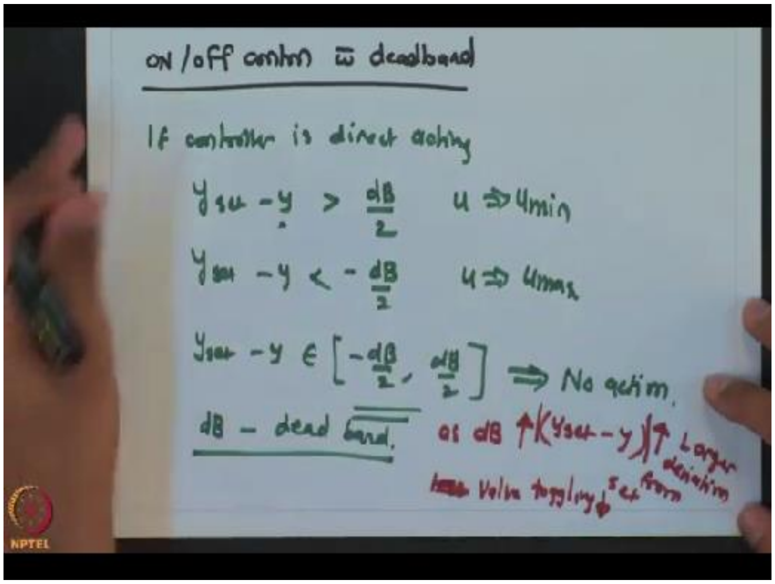
On-off control is one of the very commonly used control strategy, feedback control strategy which is for very low key objectives or very cheap control systems will have on-off control action. Let us say if you have a thermocouple temperature controller in your house, then those typically are on-off type of controller. In your lab, whenever you had some sort of a flow or a temperature controller using a small heater, those are also typically on-off type of controllers. So on-off controller, the philosophy is that the controller output depends on sign of the error. all you are interested in is what is the sign of the error. Whether the error is positive or error is negative. You do not even look at what is the magnitude of error and that is why it is very simply or easy to implement and depending on the sign of the error, control action is taken.

Let us say if the controller is direct acting and if (y_{set} – y) which is the error, if it is greater than 0, then 'u' will be equal to the minimum value of 'u'. If (y_{set} – y) is less than 0, if the error is negative, then 'u' will be made equal to the maximum value of 'u'. The exactly opposite pairing works when we have reverse acting controller. So you can see that all we are interested in is just checking what is the value of 'y' in relation to 'y_{set}'.

If 'y' is less than the set point and if the controller is direct acting, then the manipulated input is kept at its minimum value. The moment 'y' becomes greater than the set point value, the manipulated input completely shifts the direction or it goes from the minimum value to the maximum value.

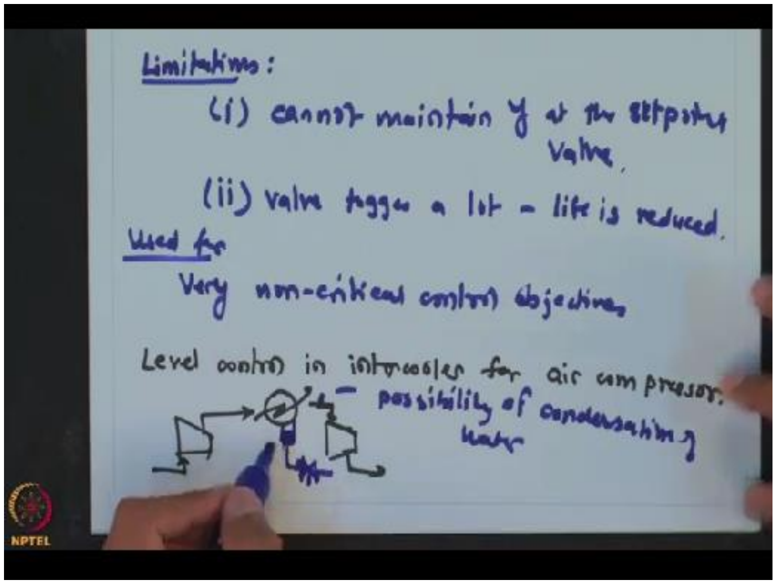
The only two values which the manipulated variable can take is the 'u_{max}' and 'u_{min}'. In typical physical systems, this 'u' or the first to the opening of a valve, some sort of a controller valve and then that means the valve will go between completely closed to completely open position. So typically this would be completely closed if it is a fail closed type of valve and this would typically mean completely open.

The valve will continuously move between the open and close. It will be toggling between the two values continuously and as there is always some lag associated with the measurement and the controller to take an action the valve to open or close, the system will never be able to reach the value of 'y_{set}'. So continuously 'y' will go above and below the set point value and the valve will keep on toggling between the close and open positions. Because of that, the valve will undergo severe wear and tear and then the valve will have to be replaced or it will have mechanical failure quite often. In order to avoid that, there is a concept of a deadband which is added to this on-off controller.



Instead of taking action as soon as ‘y’ goes below or above the set point, there is some deadband is provided between which no control action is taken. The same on-off control in the presence of deadband will look like this. If the controller is direct acting, ($y_{set} – y$), rather than greater than 0, we look at greater than some positive number. Then ‘u’ becomes ‘u_{min}’. If ($y_{set} – y$) is less than the negative of that number, ‘u’ goes to ‘u_{max}’. And then if this ($y_{set} – y$) is between these two values including 0, no action is taken. If the valve was at the, near at minimum position, it will remain at minimum. If it was at maximum position, it will remain at maximum. Because of that, during this interval or there is generally some freedom given for this ‘y’ to remain below the set point without taking any control action and this significantly reduces the toggling or the on-off moving of the valve from on to off position quite often and because of that, the valve life gets extended and this ‘dB’ is known as the deadband.

It is the band between which no controller action is taken. The larger the deadband, what is going to happen is that the valve will have less toggling but at the same time, you are allowing the output to go that, so you are allowing the output to deviate that much from the set point. So the effect of deadband is; so as the deadband increases, (y_{set} - y) increases. So that means, you will say average value of that, so that means larger deviation from the set value. But this comes at an advantage that or a valve toggling reduces. So this deadband, the higher deadband is used to avoid the valve to go from on-off position after which higher frequency. Typically the deadband is selected based on the trade-off between how my deviation is allowable and correspondingly how much valve toggling is allowed. As a trade-off between these two, the deadband gets selected. As you can see that this on-off controller is very easy to implement but it has a significant disadvantage. The two of the main disadvantages.



The first of all, it cannot maintain the set value. If we want to control the variable exactly at the set point value, then on-off controller will not be a good choice. And secondly, as the valve toggles a lot, the life of the valve is reduced. It will only be used for very non-critical control objectives where a significantly large deadband will be used to avoid the valve toggling and you are still okay by having that much of an offset.

One of the examples from real life is level control in intercooler for air compressor. So what happens is whenever you are trying to compress air from ambient conditions to some higher value, you would typically go with multi-stage compressors and as the compression of air is going to increase its temperature in order to maintain the efficiency of compression, you have to cool that air stream before it enters the next level or next compressor stage.

As we are dealing with air, air also has a capacity to hold moisture and as you compress the air and reduce the temperature after this cooler, there is a possibility of condensation of water at that point. And if we have this two phase mixture of air and water which goes into the compressor again that is very detrimental to the compressor blades. So at that point, there is a requirement that you collect this liquid and then remove this liquid after the heat exchanger.

Now as it turns out this level builds very slowly and typically there is no objective in terms of controlling this level apart from the fact that you do not want this particular vessel to get completely filled. So the level control on this particular after-cooler is typically on-off type of controller which controls a solenoid valve which is at the outlet of this.

So when this level goes beyond the certain value, this valve will open and empty out this entire contents. Again it will get closed when the level goes below the desired value. And then the system will again operate till the level gets filled up. So these kind of very low key non-critical objectives will be the places where on-off controller will be used on an industrial scale. Thank you.